Title
Evidence for Multiple Mechanisms Underlying List-Method Directed Forgetting

Journal
Proceedings of the Annual Meeting of the Cognitive Science Society, 44(44)

Authors
Dames, Hannah
Brand, Daniel
Ragni, Marco

Publication Date
2022

Peer reviewed

Evidence for Multiple Mechanisms Underlying List-Method Directed Forgetting

Hannah Dames (damesh@cs.uni-Freiburg.de)
Department of Psychology, University of Zurich, Zurich, Switzerland
Cognitive Computation Lab, Albert-Ludwigs-Universität Freiburg, Freiburg, Germany

Daniel Brand (daniel.brand@psychologie.tu-chemnitz.de)
Prädikative Verhaltensanalyse, Technische Universität Chemnitz, Chemnitz, Germany

Marco Ragni (marco.ragni@hsw.tu-chemnitz.de)
Predictive Analytics, Technische Universität Chemnitz, Chemnitz, Germany

Abstract

Directed forgetting (DF) studies demonstrate that humans can intentionally forget item information. In the presented study, participants learned three lists of words. After studying the first two lists (L0+L1), we cued half of the participants to forget these lists before learning a new list (L2), the other half remembered all three lists. Typically, such a forget instruction impedes recall of previously-studied to-be-forgotten words but enhances memory for subsequent to-be-remembered items. Instead of recalling the words, we asked participants to select the list a word was studied in, assessing how DF affected both item- and list-memory. In line with the context-change hypothesis, list-memory for L1 did not differ between the two groups suggesting that even if recall of to-be-forgotten words is typically impaired, list-memory is still intact. Furthermore, after the forget instruction, participants' list-memory was enhanced particularly for early L2 words, providing evidence for a reset of encoding or rehearsal processes.

Keywords: directed forgetting; intentional forgetting; context-change; selective rehearsal; inhibition

Introduction

Research on directed forgetting (DF) suggests that humans are able to intentionally forget previously learned information (for an overview see Bjork et al., 1998; MacLeod, 1998). Intentional forgetting is useful because it reduces interference from irrelevant information, allowing us to focus on current, relevant information. In the list-method of DF, participants are instructed to sequentially learn two lists of items. After learning the first list (referred to as L1), participants are either instructed to forget or to continue remembering that list before studying list 2 (L2). In the following memory test for both lists (irrespective of the forget or remember between-subject condition), two findings are typically observed (for a review, see Bjork et al., 1998): As illustrated in Figure 1, participants in the forget group recall fewer L1 items (called L1 forgetting) and more L2 items (L2 enhancement) than the remember group (e.g., Bjork et al., 1998; Geiselman et al., 1983; Sahakyan et al., 2013). Studies showing a dissociation between L1 forgetting and L2 enhancement effects (Pastötter & Bäuml, 2010; Sahakyan & Delaney, 2003, 2005) suggest that both retrieval and encoding processes contribute to list-method DF (see Pastötter et al., 2017a and our Predictions section for further information). Hence, in the context of list-method DF, intentional forgetting results in reduced accessibility of outdated information and enhances encoding or retrieval of newer or still relevant information. The present study tested predictions of mechanisms assumed to underly these effects by simultaneously measuring the effect of DF on both memory for items and list-membership over serial position.

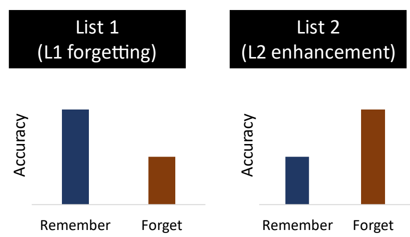

Figure 1: Typical result pattern (see e.g,, Pastötter et al., 2017) for the list-method of directed forgetting.

Theories of List-Method Directed Forgetting and the Role of Context

Our everyday life is rich with contextual information that can change rapidly (e.g., when entering a warm building in the cold winter). Our cognitive system makes use of the changes in context to drive the accessibility of our memories. That is, along with target information, context features are encoded into memory as advocated in numerous models of memory (e.g., Gillund & Shiffrin, 1984; Howard & Kahana, 2002). In the lab, fewer external contextual cues are available so that participants can often best use temporal and/or internal contextual information to probe memory (e.g., Gillund & Shiffrin, 1984; Howard & Kahana, 2002). In the present study, we assume that context features change continuously (i.e., *context drift*) not only as function of time (e.g., Brown et al., 2007; Howard & Kahana, 2002; Shiffrin & Steyvers, 1997) and/or encoded events (e.g., Sederberg et al., 2008) but also due to changes in participants' mental state (e.g., their mood; see Delaney et al., 2010). We use *context* and its contextual cues as an umbrella term including the circumstances under which a stimulus was encoded. Assuming that the occurrence of an item in a particular context is represented by a binding between features of the item and context representations (e.g., Gillund & Shiffrin, 1984; Shiffrin & Steyvers, 1997), each item is linked to a changing context. Theories aiming to explain list-method DF make different assumptions on if, and if so how, the instruction to forget affects the encoding or retrieval of such context information.

Retrieval inhibition account (e.g., Geiselman et al., 1983) Inhibitory accounts on list-method DF propose that upon the forget instruction, L1 items (and/or L1 contextual information) are inhibited, reducing access to L1 items at test (e.g., Geiselman et al., 1983). L2 enhancement effects are then attributed to reduced proactive interference from L1 items. Because to-be-forgotten items are assumed to be still available, memory performance for L1 items is only impaired in free recall but not in item recognition tests (e.g., when assuming that re-presentation restores the initial activation level of the item).

Selective rehearsal account (e.g., Bjork, 1970) According to this account, participants selectively rehearse only items that are to-be-remembered but not those that are to-be-forgotten. That is, in the context of list-method DF, participants in the remember group continue to rehearse L1 items during the encoding of L2. In contrast, participants in the forget group are assumed to stop rehearsing items of L1 upon the forget instruction and only rehearse the subsequent L2 items (thereby not further strengthening memory for L1 items, Bjork, 1970). Thus, different from the inhibition hypothesis, selective rehearsal assumes that differential encoding of L1 items contributes to L1 forgetting. L2 enhancement occurs because of reduced rehearsal load in the forget as compared to the remember group.

Context-change hypothesis (e.g., Sahakyan & Kelly, 2002) One of the most prominent theories on list-method DF assumes that L1 forgetting results from changes in participants' mental context between the study of L1 and L2 after receiving the forget instruction (context change hypothesis, introduced by Sahakyan & Kelley, 2002). According to this account, one strategy that participants use to intentionally forget L1 items in list-method DF is to deliberately change their internal context, creating a larger than normal change of context between L1 and L2 (Sahakyan & Kelley, 2002). Participants may, for instance, strategically try to think of "something else" while attempting to forget the already encoded information. As a results, the learning context of L2 items is different from the one during the study of L1 items. Because the context at test mismatches the L1 context more than it does the L2 context, recall of L1 is impeded. The most compelling evidence for the context-change hypothesis comes from the context-change paradigm introduced by Sahakyan and Kelly (2002). In their study, effects like list-method DF can be observed when between L1 and L2, instead of a forget cue, participants were instructed to imagine their life as if they were invisible (thereby actively changing their internal mental context).

The context-change and retrieval inhibition accounts are not necessarily exclusive if a mental context shift is accompanied by the inhibition of the L1 context (instead of the individual L1 items). Alternatively, without the need for inhibition, an accelerated context drift between lists upon the forget instruction (for a computational model, see Lehmann & Malmberg, 2009) could reduce the overlap of contextual features between L1 and L2. Because the test context matches the one of more recently encoded items, L1 context cues are relatively less accessible, producing L1 forgetting effects. In the present study, we tested these two possibilities.

Reset-of-encoding hypothesis (see Pastötter et al., 2017) This account suggests that after a forget instruction, encoding of early L2 items is enhanced via the reset of encoding processes (e.g., due to reduced working memory load and reduced inattention). Support for this notion comes from studies showing L2 enhancement effects particularly in the primacy part of L2 (Pastötter & Bäuml, 2010).

Challenges and the Present Study

To quantify DF, studies on list-method DF typically use general differences in recall performance of L1 and L2 between the remember and forget group. The theories introduced above can (at least in combination) account for L1 forgetting and/or L2 enhancement effects observed in recall tests. How can we distinguish between the different accounts? First, the proposed theories make different predictions concerning the strength of L1 forgetting and L2 enhancement over *serial position* of the words at study. Second, they differ with respect to which memory representations their proposed processes operate on (memory for *items* vs. memory for *item-context* bindings).

In free recall tests, output interference may contaminate the analysis of serial position. One way to control for output position is by using item-recognition tests. However, some studies suggest that L1 forgetting is absent in item-recognition (e.g., Geiselman et al., 1993; but see e.g., Benjamin, 2006; Pastötter et al., 2016; for an effect of DF on item memory for early L2 items). This is not surprising considering that some of the theories introduced above indeed predict an impact of the forget instruction on memory for the L1 item-context bindings but not the L1 items themselves. In fact, L1 forgetting can be observed in recognition tests when utilization of contextual information is promoted (Sahakyan et al., 2009), or in list discrimination tasks (Lehman & Malmberg, 2009). These findings suggest a negative effect of forgetting on memory for item-context bindings (e.g., list memory) impairing recollection (e.g., because retrieval cues are missing) but not familiarity. In contrast, other work using a multinomial modeling approach suggests that list discrimination does not differ between forget and remember groups (Sahakyan & Delaney, 2005). Therefore, it is still unclear how DF affects list memory and how its effects unravel over serial position.

To complicate the matter, many previous studies assessed the effect of DF on list memory using simple two-alternative forced choice (2AFC) tasks which required participants to indicate the list membership of a word (e.g., Lehman & Malmberg, 2009; Sahakyan & Delaney, 2005). In some experiments, participants had to decide whether a presented word belonged to one list or not (yes/no decision; Lehman & Malmberg, 2009). In other experiments, participants were asked to indicate whether a shown word was studied in L1 or L2 (Sahakyan & Delaney, 2005). Particularly in the typical two-list DF paradigm, such simple decision tasks are an impure measure of participants' memory for to-be-forgotten item-list bindings. Even if participants had poor list memory for L1 items, they may have been able to discriminate between L1 and L2 items by a process of elimination as list memory for L2 items is assumably quite high. That is, even if participants in the forget group had poor list memory for L1 items, in a 2AFC list discrimination task, they could easily reject the possibility that a shown to-be-forgotten word of L1 belongs to L2 by recalling the L2 items.

To account for this challenge, we employed a multiple-list DF paradigm with a four alternative forced choice task (4AFC) combining a list memory and item recognition test.

The present study There were three major phases in the present experiment: During the *learning phase*, participants studied three lists of 16 frequent English nouns (L0, L1, and L2). L1 and L2 parallel the typical lists in the list-method DF paradigm. Between L1 and L2, half of the participants were instructed to forget L0 and L1 (*forget* group). The other half of the participants were told to continue remembering L0 and L1 and to proceed to the second list (*remember* group). This multiple-list DF paradigm was initially introduced by Lehman and Malmberg (2009) to reduce the impact of several confounds in the traditional two-list DF method (e.g., that only L2 but not L1 receives proactive interference from a prior list) and has proven to produce reliable DF effects.

Following a distractor task, in the test phase, we tested participants' list and item memory for all of the words from the learning phase irrespective of the remember or forget instruction. For this, participants were presented with a word (from L0, L1, L2, or a new word) and were asked to indicate whether the item was presented in L0, L1, L2, or whether it was a new word. By introducing L0 items as lures for the test of L1 items, participants could not solely rely on memory for L2 items to decide whether the item in question was presented in L1 or not. This is crucial for the predictions derived from the theories in question. *Item memory* will refer to participants' likelihood to correctly identify an old item that was presented in the learning phase. *List memory* will refer to participants' likelihood to correctly select the list an item was presented in (relies on item-list bindings), given they did not respond "new". That is, to respond correctly in our test, participant had to remember the study context to differentiate the study lists.

Predictions The present study aimed to dissect list-method DF effects using a serial position analysis. Previous studies already demonstrated that L2 enhancement effects are chiefly driven by improved recall of early L2 items (e.g., Pastötter et al., 2016). However, the predictions on how DF affects list memory are less clear (the study by Lehman and Malmberg, 2009, observed no variation of L2 enhancement effects on list discrimination over serial position). Also, results for L1 forgetting over serial position are inconsistent and suffer from the methodological drawbacks pointed out before (e.g., by relying on free recall as a testing method). We aim to clarify the question how L1 forgetting and L2 enhancement of item and list memory vary over serial position. We derive predictions from the introduced accounts. Please note, that we did not consider performance for L0 within the scope of this study.

Retrieval inhibition account As detailed above, inhibitory accounts vary greatly on what representations are assumed to be inhibited upon the forget instruction. Measuring not only item but also list memory allows us to shed new light on this issue. For instance, if all L1 information (items and item-context bindings) is inhibited, then L1 forgetting should be observed for all L1 items regardless of serial position (see Geiselman et al., 1983) for both item and list memory. If only item-context bindings but not the items themselves are inhibited, then we should observe L1 forgetting only for list but not for item memory. Any modulation of L1 forgetting by serial position would be inconsistent with the classic inhibition view that the entire L1 unit is inhibited at retrieval.

Selective rehearsal account The selective rehearsal account has probably the clearest predictions regarding memory strength as a function of serial position: Because participants do not know that they can forget L1 prior to the forget instruction, they presumably rehearse L1 items until the forget instruction. If rehearsal is cumulative and stopped after the forget instruction, L1 forgetting should be largest for late L1 items as these items had the least opportunity for rehearsal. The reset of rehearsal should then enhance memory performance in particular for early L2 items. While there is plenty of evidence confirming the second prediction (L2 enhancement effects are strongest in the primacy part of L2; Pastötter et al., 2016), findings regarding the first prediction are rare and inconsistent. The selective rehearsal account makes a third interesting prediction: If participants from the remember group still rehearse L1 items during L2, the L1 items may also become associated with the context of the L2. As a consequence, list memory of L1 items should be worse in the remember than in the forget group.

Context-change hypothesis The mental context-change upon a forget instruction between L1 and L2 is assumed to segregate the two lists so that each list is associated with a different context (Sahakyan & Kelley, 2002). Impaired access to the L1 context in free recall produces L1 forgetting. In contrast, when participants in the remember group expect a memory test for the L1 items, they store and maintain L1 and L2 under similar contextual cues. We test three versions of the context-change account against each other.

Context-change via retrieval inhibition: Inhibition of L0 and L1 list-context upon the forget instruction enables participants to change their mental context (e.g., strategically think about something else). According to this hypothesis not the individual items within a list but the entire associated list context is suppressed. If so, DF should affect list memory but not item recognition of L1 words. Some may argue that the re-presentation of an item somehow also releases the inhibition of its associated list-context but, following that line of reasoning, one must wonder how to test/falsify inhibition then in general. No serial position effects are predicted.

Context-change via an accelerated context drift: In the forget condition, an accelerated context drift between L1 and L2 enhances list discrimination of L2 items at test (Lehmann & Malmberg, 2009). Predictions for L1 list memory are not clear-cut: On the one hand, list memory for L0 and L1 could be worse in the forget as compared to the remember group because their contexts are less correlated with the one at test. Although this should affect freerecall of words, it is unclear how reduced similarity between the study and test contexts should affect list memory performance. If we assume that the current test context is used to retrieve the list-membership associated to a word, performance for L1 items should be worse in the forget than in the remember group. If not, performance should be equal.

On the other hand, it could be argued that by accelerating the context drift between L1 and L2, list discrimination is enhanced not only for L2 but also for late L1 items because these items do not share as much context overlap with other items as L0 or early L1 items. If so, we should observe reduced or even reversed L1 forgetting effects on list memory particularly in the recency part of L1.

Context-change via tagging: Not only items from L2 become associated with a new context but also L0 and L1 items are tagged to-be-forgotten upon a forget instruction producing L1 and L2 enhancement effects for list memory. If the complete learning unit (L0 and L1, as well as L2) becomes tagged in such a way, then the strength of these effects should not vary over serial position. If the tagging of L1 items is stronger for recent items (e.g., still active in working memory), then the most recent items should be stronger associated with the forget context as compared to early items. As a result, list memory should be strongest for late to-be-forgotten L1 items.

Reset-of-encoding hypothesis (see Pastötter et al., 2017)**.** If the reset of encoding processes does not only affect memory for subsequent items but also for bindings, both item and list memory for L2 should be better in the forget as compared to the remember condition. These L2 enhancement effects should particularly occur in the primacy part of L2.

Method

Participants

In total, 179 native English speakers completed the whole experiment via the web-based participation platform Prolific. Half of the participants were randomly assigned to the remember condition, and the other half to the forget condition. After applying the following exclusion criteria, the final sample consisted of 100 participants (M_{age} = 30.1, SD_{age} = 6.3, range 19–40 years; 62% female, 34% male, 4% diverse): We excluded participants who failed an easy attention check in the middle of the experiment (n = 16), who said they did not participate seriously in the study (n = 3), who used external help (e.g., pen and paper) to complete the task (n = 26), who had an error rate of more than 90% for L2 items (n = 3), who had technical issues during completion (n = 1), who strongly suspected that to-be-forgotten stimuli would be tested (n = 10), or who did not follow the forget instruction (n = 4). All these participants were excluded and replaced.

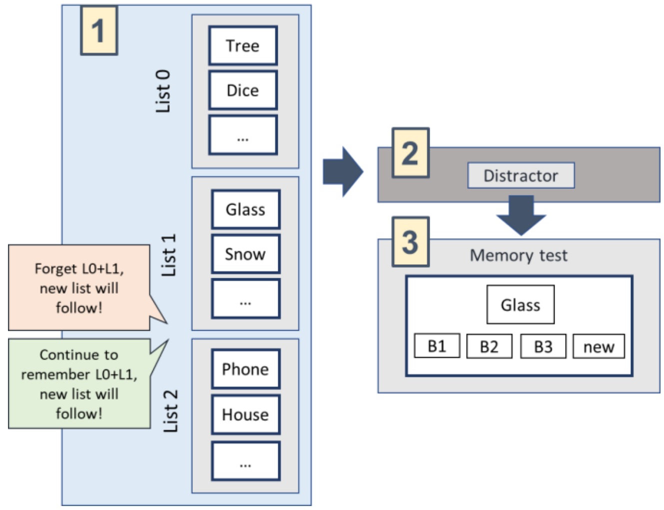

Figure 2: Experimental procedure.
B1 = Block 1, B2 = Block 2, B3 = Bock 3

Trial Structure and Procedure

The experiment was programmed using jsPsych (de Leeuw, 2015). For every participant, 64 frequent English nouns (length of 4-5 letters) were randomly drawn from a pool of 600 words. Participants' task was to remember the words for a later memory test. As illustrated in Figure 2, the experiment consisted of three phases.

Learning phase For the learning phase, we used a variation of the traditional two-list DF list-method procedure where instead of two lists, participants were asked to remember three lists of 16 words (Lehman & Malmberg, 2009): List 0 (L0), List 1 (L1), and List 2 (L2). Words were presented in the middle of the screen for 4s each. The presentation of each word was preceded by a 500ms fixation cross. Following Lehman and Malmberg's (2009) approach, all participants were told that they will learn three lists of words but that they would only have to remember one of the lists for a later memory test. However, they would be told only later in the experiment which list they should remember. After each list, participants were informed that they had completed the first/second list and that they should try to remember the following words as well as possible. After presentation of L1 (the second list), only the forget group was told that they will only have to remember the next list and that, hence, the old two lists do not matter anymore. That is, half of the participants received a forget instruction between L1 and L2 whereas the remaining half remembered all lists.

Distractor phase Following L2, to purge working memory, participants worked on a distractor task (a computerized version of the Corsi block-tapping Task; CORSI; forward span; Corsi, 1973) for 1.5 mins.

Test phase Next, in the test phase, participants were presented with all words from all lists regardless of the remember and forget instruction. In addition, we presented 16 new items. Participants were asked to select the block the presented word was previously presented in or indicate that it was a new word. Thus, there were four response options: First block, second block, third block, or new item. Participants in the forget condition were explicitly informed that although they were told they could forget the first two blocks, they should now try to remember the images from all the blocks. At the end of the experiment, participants were properly debriefed about the false memory instruction and its reason.

Results

All new words were excluded from the analyses. We measured item memory by participants' likelihood to correctly identify a previously studied word as old (responded that the word was presented in L0, L1, or L2; p(old)). We measured list memory by participants' likelihood to select the correct list the word was studied in, given they did not respond "new" (p(correct|old)). If item memory was unaffected by DF, participants should rarely categorize to-be-forgotten L1 words as a new. If DF weakened list memory, they should struggle to correctly discriminate between the lists. We analyzed p(old) and p(correct|old) using separate Bayesian generalized linear mixed models (BGLMMs) for items studied in L1 as well as L2 assuming a Bernoulli data distribution predicted by a linear model through a logistic link function (via *R* package *brms*; Bürkner, 2018). For the regression coefficients of the accuracy analyses, we used moderately informative Cauchy priors with a scale of 0.353 and a mean of 0 (recently proposed default priors for logistic models; Oberauer, 2019). The categorical predictor *memory instruction* was coded as sum-to-zero contrasts and the continuous predictor *serial position* was mean-centered. All our models included the fixed factors instruction (remember vs. forget, between-subject), serial position, and their interaction as well as random intercepts for participants. We computed Bayes Factors (BFs) to estimate the strength of evidence for the null and the alternative hypothesis. For this, we compared one model that included the factor of interest to one that did not. We considered a BF10 larger than 3 as substantial evidence for the alternative hypothesis and a BF01 larger than 3 as substantial evidence for the null hypothesis.

L1 forgetting For L1, there was no main effect of memory instruction, neither for item (BF_{01} = 5.0) nor for list (BF_{01} = 4.7) memory. We found inconclusive evidence for an effect of serial position on item memory (BF_{01} = 1.4) and no evidence for an effect on list memory (BF_{01} = 4.1). Crucially, however, we observed an interaction between memory instruction and serial position for item (BF_{10} = 25.0) but not

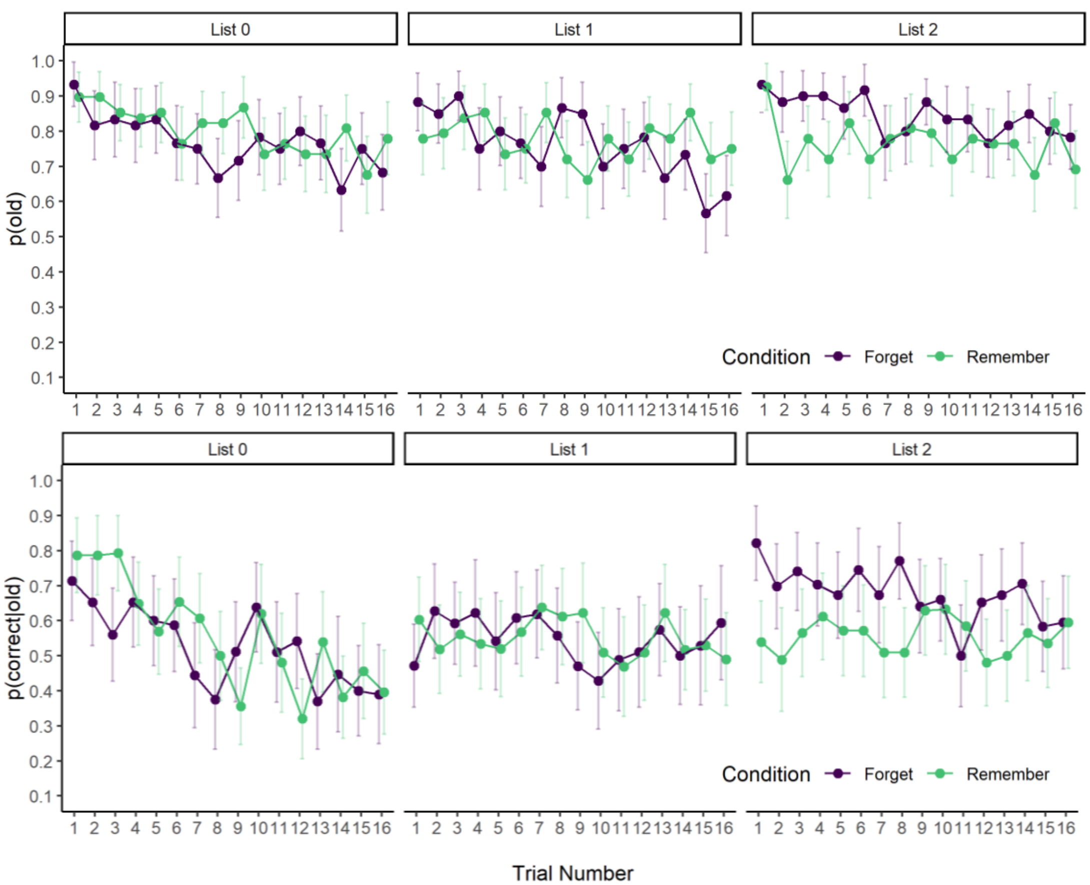

Figure 3: Item (top) and list (bottom) memory as a function of memory instruction (condition), list, and serial position. Error bars present the 95% confidence intervals.

for list memory (BF_{01} = 8.2). Thus, we found evidence against L1 forgetting for list memory. As illustrated in Figure 3, DF on item memory was mainly observed for late L1 items.

L2 enhancement Both L2 item (BF_{10} = 11.7) and list (BF_{10} = 16.4) memory was substantially better for the forget as compared to the remember group. We found evidence for a main effect of serial position for item (BF_{10} = 11.7) but not for list (BF_{10} = 0.8, inconclusive) memory. As evidence for an interaction between serial position and instruction was inconclusive (item: BF_{01} = 1.6, list: BF_{01} = 1.8), we specifically tested whether L2 enhancement effects would be present in the first and/or last four trials of L2. As illustrated in Figure 3, L2 enhancement effects for list (BF_{10} = 29.1) and item (BF_{10} = 33.0) memory were present for early L2 items, but evidence for an effect of memory instruction was inconclusive for later L2 items (list: BF_{01} = 1.3; item: BF_{01} = 1.2).

Discussion

We tested how Directed Forgetting (DF) affected item as well as list memory and whether the effects varied over serial position. Doing so allowed us to test predictions derived from current theories on list-method DF against each other. Using a multiple-list DF approach (Lehman & Malmberg, 2009), participants learned three lists (L0, L1, and L2). Between L1 and L2, half of the participants were told to remember only L2 (and, hence, forget L0+L1), whereas the other half of the participants were told to remember all three lists. At test, participants' memory was tested for all words, irrespective of the memory instruction. Typically, a list-method forget instruction impairs free recall performance of the previous to-be-forgotten words (called *L1 forgetting*) but enhances memory for the subsequent L2 items (*L2 enhancement*).

In the present study, DF impaired item memory but only for late L1 items. Like previous studies (e.g., Sahakyan et al., 2009), this result challenges the general assumption that DF does not affect performance in item recognition tests. In contrast, we provide Bayesian evidence against an effect of DF on L1 list memory (and against a modulation of DF on list memory over serial position). Moreover, we observed L2 enhancement effects not only for item (e.g., Pastötter et al., 2016) but also for list memory. That is, participants in the forget group were better at (1) recognizing old L2 items as previously-studied items and at (2) selecting the list they studied L2 items in.

Crucially, L2 list and item memory enhancement effects were stronger for early L2 items as compared to late L2 items. This pattern of results provides strong evidence for the notion that after a forget instruction, encoding processes or rehearsal are reset, enhancing the encoding of early L2 items (e.g., due to reduced working memory load or reduced inattention; see Pastötter et al., 2017). Our study extends previous findings showing that the reset of encoding (or rehearsal) processes facilitates not only encoding of subsequent items (Pastötter & Bäuml, 2010) but also their item-list bindings. Note that, without the assumption that item-list bindings contribute to recognition memory, increased list discriminability of early L2 items (as proposed by the tagging or context-drift version of the context-change hypothesis) cannot explain the observed L2 enhancement effects for item memory.

The observed decreasing slope for L1 item memory in the forget but not the remember group was only predicted by the selective rehearsal account (Bjork, 1970). This account assumes that until the forget instruction, participants rehearse L1 items. Hence, only early but not late L1 items benefit from rehearsal prior to the forget instruction. Yet, this account fails to explain why rehearsal did not impact list memory in L1. Potentially, rehearsal did not strengthen list-word bindings. If so, however, selective rehearsal cannot account for the observed L2 enhancement effects for list memory.

The absent L1 forgetting for list memory also speaks against better list discrimination for (late) L1 items as proposed by the tagging-hypothesis or by an accelerated context-drift. Further, if the entire L1 list-context was inhibited upon the forget instruction (as proposed by the context-change via retrieval-inhibition hypothesis), we would have expected that participants had difficulties to remember what list an item was studied in, which was not the case. Generally, our findings support the notion that in list-method DF, word-list bindings for to-be-forgotten words are still intact. Hence, the impeded free recall performance of to-be-forgotten words observed in previous studies – which has been associated with impaired item-context memory – may in fact be due to difficulties accessing that information. Superficially, this idea appears to be in line with the context-change account. It is, however, only agreeable with the context-drift version of the account, under the assumption that the similarity between study and list contexts does not help performance in a list discrimination task. If it were, list memory for late L1 items in the forget group should have been better than for early L1 items, because late L1 items share less contextual overlap with other items. Of course, if that were the case, enhanced list discrimination fails to explain the observed L2 enhancement effects on list memory.

In conclusion, none of the proposed accounts can explain the full pattern of results. Our findings therefore suggest that multiple mechanisms underly list-method DF:

(1) One process produces better recognition memory for recent L1 items in the remember as compared to the forget group (e.g., stopping rehearsal so that late to-be-forgotten items have less opportunity for rehearsal).
(2) Previous studies consistently observed worse recall performance of L1 items after a forget instruction (for a review, see Bjork et al, 1998), suggesting that DF impairs access to the L1 study context. Because our results show that memory list membership is still intact after a forget instruction, this process does not rely on tagging or inhibition but rather on an accelerated context-drift upon the forget instruction (Lehman & Malmberg, 2009; i.e., an internal context-change, Sahakyan & Kelley, 2002).
(3) Upon the forget instruction, encoding or rehearsal processes are reset (see Pastötter et al., 2017), enhancing memory for subsequent items and item-list bindings.

Acknowledgments

This research was supported by the German Research Foundation, DFG (Grant RA1934/5-1 and RA1934/8-1) within the SPP 1921 "Intentional Forgetting". We are grateful to Marie Jakob for her support when programming the experiment.

References

Benjamin, A. S. (2006). The effects of list-method directed forgetting on recognition memory. *Psychonomic Bulletin & Review*, *13*(5), 831–836. https://doi.org/10.3758/BF03194005

Bjork, E. L., Bjork, R. A., & Anderson, M. C. (1998). Varieties of goal-directed forgetting. *Intentional Forgetting: Interdisciplinary Approaches.*, 103–137.

Bjork, R. A. (1970). Positive forgetting: The noninterference of items intentionally forgotten. *Journal of Verbal Learning and Verbal Behavior*, *9*(3), 255–268. https://doi.org/10.1016/S0022-5371(70)80059-7

Brown, G. D. A., Neath, I., & Chater, N. (2007). A temporal ratio model of memory. *Psychological Review*, *114*(3), 539–576. https://doi.org/10.1037/0033-295X.114.3.539

Corsi, P. M. (1973). *Human memory and the medial temporal region of the brain* (Vol. 34, Issues 2-B, p. 891). ProQuest Information & Learning.

Delaney, P. F., Sahakyan, L., Kelley, C. M., & Zimmerman, C. A. (2010). Remembering to Forget: The Amnesic Effect of Daydreaming. *Psychological Science*, *21*(7), 1036–1042. https://doi.org/10.1177/0956797610374739

Geiselman, R. E., Bjork, R. A., & Fishman, D. L. (1983). Disrupted retrieval in directed forgetting: A link with posthypnotic amnesia. *Journal of Experimental Psychology: General*, *112*(1), 58–72. https://doi.org/10.1037/0096-3445.112.1.58

Gillund, G., & Shiffrin, R. M. (1984). A retrieval model for both recognition and recall. *Psychological Review*, *91*(1), 1–67. https://doi.org/10.1037/0033-295X.91.1.1

MacLeod, C. M. (1998). Directed forgetting. In J. M. Golding & C. M. MacLeod (Eds.), *Intentional forgetting: Interdisciplinary approaches* (pp. 1–57). Mahwah, NJ: Erlbaum.

Howard, M. W., & Kahana, M. J. (2002). A Distributed Representation of Temporal Context. *Journal of Mathematical Psychology*, *46*(3), 269–299. https://doi.org/10.1006/jmps.2001.1388

Lehman, M., & Malmberg, K. J. (2009). A global theory of remembering and forgetting from multiple lists. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *35*(4), 970–988. https://doi.org/10.1037/a0015728

Pastötter, B., & Bäuml, K.-H. (2010). Amount of postcue encoding predicts amount of directed forgetting. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *36*(1), 54–65. https://doi.org/10.1037/a0017406

Pastötter, B., Kliegl, O., & Bäuml, K.-H. T. (2016). List-method directed forgetting: Evidence for the reset-of-encoding hypothesis employing item-recognition testing. *Memory*, *24*(1), 63–74. https://doi.org/10.1080/09658211.2014.985589

Pastötter, B., Tempel, T., & Bäuml, K.-H. T. (2017a). Long-Term Memory Updating: The Reset-of-Encoding Hypothesis in List-Method Directed Forgetting. *Frontiers in Psychology*, *8*. https://www.frontiersin.org/article/10.3389/fpsyg.2017.02076

Pastötter, B., Tempel, T., & Bäuml, K.-H. T. (2017b). Long-Term Memory Updating: The Reset-of-Encoding Hypothesis in List-Method Directed Forgetting. *Frontiers in Psychology*, *8*, 2076. https://doi.org/10.3389/fpsyg.2017.02076

Sahakyan, L., & Delaney, P. F. (2003). Can encoding differences explain the benefits of directed forgetting in the list method paradigm? *Journal of Memory and Language*, *48*(1), 195–206. https://doi.org/10.1016/S0749-596X(02)00524-7

Sahakyan, L., & Delaney, P. F. (2005). Directed Forgetting in Incidental Learning and Recognition Testing: Support for a Two-Factor Account. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *31*(4), 789–801. https://doi.org/10.1037/0278-7393.31.4.789

Sahakyan, L., Delaney, P. F., Foster, N. L., & Abushanab, B. (2013). Chapter Four - List-Method Directed Forgetting in Cognitive and Clinical Research: A Theoretical and Methodological Review. In B. H. Ross (Ed.), *Psychology of Learning and Motivation* (Vol. 59, pp. 131–189). Academic Press. https://doi.org/10.1016/B978-0-12-407187-2.00004-6

Sahakyan, L., & Kelley, C. M. (2002). A contextual change account of the directed forgetting effect. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *28*(6), 1064–1072. https://doi.org/10.1037/0278-7393.28.6.1064

Sahakyan, L., Waldum, E. R., Benjamin, A. S., & Bickett, S. P. (2009). Where is the forgetting with list-method directed forgetting in recognition? *Memory & Cognition*, *37*(4), 464–476. https://doi.org/10.3758/MC.37.4.464

Sederberg, P. B., Howard, M. W., & Kahana, M. J. (2008). A context-based theory of recency and contiguity in free recall. *Psychological Review*, *115*(4), 893–912. https://doi.org/10.1037/a0013396

Shiffrin, R. M., & Steyvers, M. (1997). A model for recognition memory: REM—retrieving effectively from memory. *Psychonomic Bulletin & Review*, *4*(2), 145–166. https://doi.org/10.3758/BF03209391